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Optic Nerve Sheath Distention as a Protective Mechanism Against the Visual Impairment and Intracranial Pressure Syndrome in Astronauts

As nicely reported by Mader et al.,^{1,2} a significant proportion of the astronauts who spend extended periods in microgravity develop ophthalmic abnormalities, including optic nerve sheath (ONS) distention, optic disc swelling, globe flattening, choroidal folds, and hyperopic shifts, which is also designated as visual impairment and intracranial pressure (VIIP) syndrome. Importantly, astronauts with VIIP can experience decreases in visual acuity that remain unresolved years after flight.² Given that the VIIP syndrome is one of the top priorities for the National Aeronautics and Space Administration, especially in view of future long-duration spaceflight missions, including trips to Mars, there is an urgent need to better understand the mechanisms leading to VIIP and to develop countermeasure strategies.

Currently, the exact mechanisms causing the VIIP syndrome are unknown. Among the several mechanisms proposed to play a role, a leading hypothesis is that the VIIP syndrome is caused by elevated intracranial pressure (ICP) resulting from microgravity-induced cephalad fluid shifts leading to venous stasis in the head and neck.³ This stasis could cause impairment of cerebrospinal fluid (CSF) drainage into the venous system and cerebral venous congestion, both of which could lead to a rise in ICP.³ The increased subarachnoid pressure resulting from intracranial hypertension is thought to be directly transmitted from the intracranial compartment to the intraorbital compartment through the peripoptic subarachnoid space (SAS).² This elevated CSF pressure at eye level results in ONS distention and anteriorly directed forces that indent the posterior sclera resulting in posterior globe flattening, redundancy and folding of the choroid, and axial shortening.² In addition, elevated ICP could result in stasis of axoplasmic flow with optic disc swelling similar to what occurs in patients with terrestrial idiopathic intracranial hypertension.³

In the present letter, we provide a conceptual framework in which ONS distention may be seen as a compensatory protection mechanism against the other ophthalmic changes of the VIIP syndrome. As noted above, the rise in ICP, resulting from microgravity-induced cephalad fluid shifts, would presumably be propagated from the CSF surrounding the brain down the ONSs to the posterior globe, ultimately resulting in the ophthalmic abnormalities of the VIIP syndrome.¹ However, we believe that the ONS response to the rise in ICP during extended microgravity exposure may play a prominent role in determining whether or not an astronaut is susceptible to developing ophthalmic changes of VIIP. It is important to note that elevated CSF pressure results in dilation of the ONS before papilledema appears.⁴ Furthermore, a previous study among patients undergoing intrathecal infusion testing showed that the ONS response measured with ultrasonography was directly correlated with CSF pressure above an individual patient's threshold until a saturation point was reached when no further dilation occurred.⁵ Importantly, comparison of the pressure response in 12 patients showed that changes in ONS diameter were predictable within the same patient but varied interindividually with respect to the relative change in ONS diameter per pressure unit and the range of operation (threshold and saturation).⁵ In three patients, the ONS diameter remained constant while the CSF pressure rose at maximum infusion to peak levels, which resembled a saturation effect.⁵ Saturation of

the response occurred between 30 and 40 mm Hg.⁵ In the remaining cases, however, the authors were not able to detect this phenomenon within the pressure range studied.⁵ The authors proposed that the ONS saturation effect may relate to radially oriented trabecular fibers that traverse the SAS and connect pia mater of the optic nerve with the innermost arachnoid layer of the sheath.⁵ We hypothesize that astronauts with lower relative CSF pressures at saturation of the ONS response may be more likely to develop ophthalmic abnormalities of VIIP. In these subjects, ONS expansion will reach a maximum capacity more rapidly (at lower CSF pressure), and, as this compensatory mechanism reaches its limit, small changes in CSF volume may elicit high increases in CSF pressure in the ONS. It could be argued that the saturation of the ONS response (constant ONS diameter) may activate the recruitment of compensating routes for CSF drainage in an attempt to stabilize the CSF pressure at eye level. However, such alternative compensatory mechanisms may be limited. It is highly unlikely that the CSF once in the orbital CSF space can change its direction of flow from the SAS of the optic nerve toward the intracranial SAS,⁶ given the microgravity-induced redistribution of CSF volume from the spinal canal to the cranium.⁷ Lymphatics in the dura of the human optic nerve have been proposed as a possible outflow pathway for CSF from the SAS of the optic nerve.^{6,8} However, these orbital optic nerve lymphatic drainage systems may be affected by microgravity-induced cephalad fluid shifts, which could lead to lymph stasis.² Therefore, once the limits of compensation by ONS expansion have been reached, progressively smaller increases in CSF volume will be associated with significant increases in CSF pressure in the ONS, resulting in ophthalmic changes including optic disc swelling, globe flattening, choroidal folds, and hyperopic shifts. This would mean that astronauts who reach their saturation point at a lower relative CSF pressure would be at highest risk for developing VIIP.

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